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# Effective Charges of Neutral Atoms in Distant Collisions (Commemoration Issue Dedicated to Professor Takuji Yanabu on the Occasion of his Retirement)

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NOTE

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In the classical picture of atom the electronic screening of nuclear charge is depicted as follows; all atomic electrons make their orbital motions many times around the atomic nucleus, so that each orbital electron is regarded as a closed shell with electronic charge surrounding the atomic nucleus. If the observation time is small compared to the periods of orbital motions for some electrons, the screening effect of these electrons are incomplete, and some effective charge should be observed even for a neutral atom.

In the fast collision between a projectile particle and a neutral target atom, where the effective interaction time corresponds to the observation time, this kind of effective charge is expected to reveal itself. When a projectile with velocity  $v(=av_0$ , where  $v_0$  is Bohr velocity) pass through straight at the distance  $R(=ka_0$ , where  $a_0$  is Bohr radius) from a target atom, the interaction time is given by

$$t=2R/v=2(k/\alpha)(a_0/v_0). \quad (1)$$

The period of orbital motion  $t_i$  for  $i$ -th electron of which orbital radius and velocity are  $a_i$  and  $v_i$ , respectively, is given by

$$t_i=2\pi a_i/v_i. \quad (2)$$

The screening is complete if  $t>t_i$ , and incomplete if  $t<t_i$ . In the latter case, for simplicity, we assume the screening is such that only  $t/t_i$  times of electronic charge is present in the corresponding closed shell. Then, effective charge  $Z_{eff}$  of a neutral target atom with atomic number  $Z_T$  is expressed as

$$Z_{eff}=Z_T-\sum_i n_i-\sum_j (t/t_j)n_j, \quad (3)$$

where the second term in the right hand side is summed over all orbital electrons with  $t>t_i$ , and the third term over all orbital electrons with  $t<t_j$ .

The effective charge  $Z_{eff}$  of eq. (3) are calculated with the values of orbital velocities and radii given by Desclaux.<sup>1)</sup> The effective charges  $Z_{eff}$  are shown in Fig. 1 as a function of  $k/\alpha$  for  $Z_T=10, 20, 30, 40$  and  $50$ . In this figure, the scales of projectile energies for some collision distances are also given. The present calculation gives the false result that  $Z_{eff}$  approaches to  $Z_T$  at large projectile energies. However, overall

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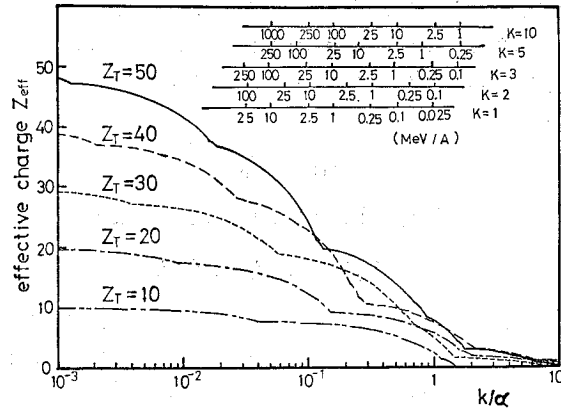


Fig. 1. Effective charges of neutral atoms seen by a fast projectile as a function of parameter  $k/\alpha$ , where  $k$  is the impact parameter in unit of Bohr radius and  $\alpha$  the projectile velocity in unit of Bohr velocity.

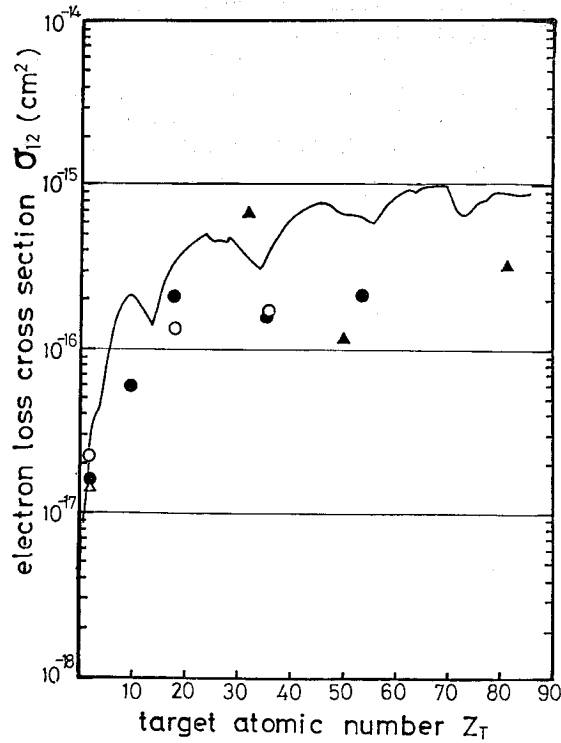


Fig. 2. Electron loss cross sections of 1 MeV  $\text{He}^+$  ions for various neutral target atoms. Experimental data are given by Pivovar et al ( $\circ$ , ref. 3 and 4), Itoh et al ( $\triangle$ , ref. 5), Kanamori et al ( $\blacktriangle$ , ref. 6) and T. Kido ( $\bullet$ , ref. 7).

feature of  $Z_{eff}$  gives some clue for investigation of distant collisions with neutral atoms.

As an example of application of this effective charge, the electron loss cross section  $\sigma_{12}$  of 1 MeV  $\text{He}^+$  ion for various target atoms are calculated on the basis of binary encounter approximation.<sup>2)</sup> The loss cross section is expressed with the maximum ionizable distance  $R_m$ ,

$$\sigma_{12} = \pi R_m^2. \quad (4)$$

The distance  $R_m$  is determined by solving the following equation,

$$I = 2Z_{eff}^2(R_m, v) e^4 / (m_e v^2 R_m^2), \quad (5)$$

where  $m_e$  is electron mass and  $I$  is the ionization energy of  $\text{He}^+$ . The result is shown in Fig. 2. The calculated cross sections are fairly in good agreement with experimental ones<sup>3-7)</sup> with respect to the order of magnitude as well as the trend of increase with  $Z_T$ . There is very interesting oscillation with  $Z_T$  in the calculated cross sections. Experiments over wide range of target atoms are desired to clarify this oscillation.

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